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**1.3 μm dissipative soliton resonance generation in Bismuth doped fiber laser**

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**Abstract**
In this work, a Figure-9 (F9) bismuth-doped fiber laser (BiDFL) operating in the dissipative soliton resonance (DSR) regime is presented. The 1338 nm laser used a BiDF as the active gain medium, while a nonlinear amplifying loop mirror (NALM) in an F9 configuration was employed to obtain high energy mode-locked pulses. The wave breaking-free rectangular pulse widened significantly in the time domain with the increase of the pump power while maintaining an almost constant peak power of 0.6 W. At the maximum pump power, the mode-locked laser delivered a rectangular-shaped pulse with a duration of 48 ns, repetition rate of 362 kHz and a radio-frequency signal-to-noise ratio of more than 60 dB. The maximum output power was recorded at around 11 mW with a corresponding pulse energy of 30 nJ. This is, to the best of the author's knowledge, the highest mode-locked pulse energy obtained at 1.3 μm as well as the demonstration of an NALM BiDFL in a F9 configuration. © 2021, The Author(s).

**References**

- Gattass, R.R., Mazur, E.
  **Femtosecond laser micromachining in transparent materials**
  (2008) *Nat. Photon.*, 2, pp. 219-225.
  COI: 1:CAS:528:DC%2BD1cXltVOgsbk%3D

- Morin, F., Druon, F., Hanna, M., Georges, P.
  **Microjoule femtosecond fiber laser at 1.6 μm for corneal surgery applications**
  (2009) *Opt. Lett.*, 34, pp. 1991-1993.
  &

- Merker, M., Ackermann, R., Kammel, R., Kunert, K.S., Nolte, S.
  **An in vitro study on focusing fs-laser pulses into ocular media for ophthalmic surgery**
  (2013) *Lasers Surg. Med.*, 45, pp. 589-596.
  PID: 24105636

- Salem, R.
  **Mid-infrared supercontinuum generation spanning 1.8 octaves using step-index indium fluoride fiber pumped by a femtosecond fiber laser near 2 μm**
  (2015) *Opt. Express*, 23, pp. 30592-30602.

- Diddams, S.A., Hollberg, L., Mbele, V.
  **Molecular fingerprinting with the resolved modes of a femtosecond laser frequency comb**
  (2007) *Nature*, 445, pp. 627-630.

COI: 1:CAS:528:DC%2BD2sXhtlOrtb0%3D, PID: 17287805

- Xu, C., Wise, F.W.
**Recent advances in fibre lasers for nonlinear microscopy**
(2013) *Nat. Photon.*, 7, pp. 875-882.
COI: 1:CAS:528:DC%2BC3sXhs1CitbrM

- Kaplan, A.M., Agrawal, G.P., Maywar, D.N.
**Optical square-wave clock generation based on an all-optical flip-flop**
(2010) *IEEE Photon. Technol. Lett.*, 22, pp. 489-491.

- Özgören, K., Öktem, B., Yilmaz, S., Ilday, F.Ö., Eken, K.
**83 W, 3.1 MHz, square-shaped, 1 ns-pulsed all-fiber-integrated laser for micromachining**
(2011) *Opt. Express*, 19, pp. 17647-17652.
&

- Cranch, G.A., Flockhart, G.M.H., Kirkendall, C.K.
**Efficient fiber Bragg grating and fiber Fabry-Perot sensor multiplexing scheme using a broadband pulsed mode-locked laser**
(2005) *J. Light. Technol.*, 23, p. 3798.

- Chang, W., Ankiewicz, A., Soto-Crespo, J.M., Akhmediev, N.
**Dissipative soliton resonances**
(2008) *Phys. Rev. A*, 78, p. 23830.
COI: 1:CAS:528:DC%2BD1cXhtVKjsbjP

- Dvoretskiy, D.A.
**High-energy, sub-100 fs, all-fiber stretched-pulse mode-locked Er-doped ring laser with a highly-nonlinear resonator**
(2015) *Opt. Express*, 23, pp. 33295-33300.
PID: 26831994

- Wang, J.
**High energy soliton pulse generation by a magnetron-sputtering-deposition-grown MoTe 2 saturable absorber**
(2018) *Photon. Res.*, 6, pp. 535-541.
COI: 1:CAS:528:DC%2BC1MXkvVKntrc%3D

- Buckley, J.R., Wise, F.W., Ilday, F.Ö., Sosnowski, T.
**Femtosecond fiber lasers with pulse energies above 10? nJ**
(2005) *Opt. Lett.*, 30, pp. 1888-1890.
COI: 1:STN:280:DC%2BD2Mvis1ClsQ%3D%3D, PID: 16092379

- Nie, B., Pestov, D., Wise, F.W., Dantus, M.
**Generation of 42-fs and 10-nJ pulses from a fiber laser with self-similar evolution in the gain segment**
(2011) *Opt. Express*, 19, pp. 12074-12080.
COI: 1:CAS:528:DC%2BC3MXotFamsbY%3D, PID: 21716443

- Liu, H., Liu, Z., Lamb, E.S., Wise, F.
**Self-similar erbium-doped fiber laser with large normal dispersion**
(2014) *Opt. Lett.*, 39, pp. 1019-1021.
COI: 1:CAS:528:DC%2BC2cXotlOis70%3D, PID: 24562267

- Ilday, F.Ö., Wise, F.W., Sosnowski, T.
  **High-energy femtosecond stretched-pulse fiber laser with a nonlinear optical loop mirror**
  (2002) *Opt. Lett.*, 27, pp. 1531-1533.
  COI: 1:STN:280:DC%2BD2snptVaksA%3D%3D, PID: 18026496

- Grelu, P., Akhmediev, N.
  **Dissipative solitons for mode-locked lasers**
  (2012) *Nat. Photon.*, 6, pp. 84-92.
  COI: 1:CAS:528:DC%2BC38Xhs1Gis7w%3D

- Li, D.
  **Characterization and compression of dissipative-soliton-resonance pulses in fiber lasers**
  (2016) *Nat. Publ. Gr.*, pp. 1-7.

- Wu, X., Tang, D.Y., Zhang, H., Zhao, L.M.
  **Dissipative soliton resonance in an all-normaldispersion erbium-doped fiber laser**
  (2009) *Opt. Express*, 17, p. 5580.
  COI: 1:CAS:528:DC%2BD1MXktl2ru7w%3D, PID: 19333325

- Duan, L., Liu, X., Mao, D., Wang, L., Wang, G.
  **Experimental observation of dissipative soliton resonance in an anomalous-dispersion fiber laser**
  (2012) *Opt. Express*, 20, pp. 265-270.
  COI: 1:CAS:528:DC%2BC38XpvVamuw%3D%3D, PID: 22274349

- Lee, J., Koo, J., Lee, J.H.
  **A pulse-width-tunable, mode-locked fiber laser based on dissipative soliton resonance using a bulk-structured Bi<sub>2</sub>Te<sub>3</sub> topological insulator**
  (2016) *Opt. Eng.*, 55, p. 81309.

- Luo, Z.
  **Pulse dynamics of dissipative soliton resonance with large duration-tuning range in a fiber ring laser**
  (2012) *Opt. Lett.*, 37, pp. 4777-4779.
  PID: 23164910

- Yang, J.H.
  **Observation of dissipative soliton resonance in a net-normal dispersion figure-of-eight fiber laser**
  (2013) *IEEE Photon. J.*, 5.

- Wang, S.-K.
  **Dissipative soliton resonance in a passively mode-locked figure-eight fiber laser**
  (2013) *Opt. Express*, 21, p. 2402.
  PID: 23389220

- Krzempek, K., Abramski, K.
  **6.5 μJ pulses from a compact dissipative soliton resonance mode-locked erbium–ytterbium double clad (DC) laser**
  (2016) *Laser Phys. Lett.*, 14, p. 15101.

- Krzempek, K., Abramski, K.
  **Dissipative soliton resonance mode-locked double clad Er:Yb laser at different values of anomalous dispersion**
  (2016) *Opt. Express*, 24, pp. 22379-22386.
  COI: 1:CAS:528:DC%2BC1cXltVWhurc%3D, PID: 27828309

- Semaan, G., Braham, F.B., Salhi, M., Meng, Y., Sanchez, F.
  **Generation of high energy square-wave pulses in all anomalous dispersion Erâ€¯:Yb passive mode locked fiber ring laser**
  (2016) *Opt. Express*, 24, pp. 4777-4779.

- Krzempek, K., Sotor, J., Krzysztof, A.
  **Compact all-fiber figure-9 dissipative soliton resonance mode-locked double-clad Er:Yb laser**
  (2016) *Opt. Lett.*, 41, pp. 4995-4998.
  COI: 1:CAS:528:DC%2BC1cXlsVaqtbw%3D, PID: 27805668

- Krzempek, K., Tomaszewska, D., Abramski, K.M.
  **Dissipative soliton resonance mode-locked all-polarization-maintaining double clad Er: Yb fiber laser**
  (2017) *Opt. Express*, 25, pp. 10906-10913.

- Du, T.
  **1.2-W average-power, 700-W peak-power, 100-ps dissipative soliton resonance in a compact Er:Yb co-doped double-clad fiber laser**
  (2017) *Opt. Lett.*, 42, pp. 462-465.

- Krzempek, K.
  **Dissipative soliton resonances in all-fiber Er-Yb double clad figure-8 laser**
  (2015) *Opt. Express*, 23, pp. 30651-30656.
  COI: 1:CAS:528:DC%2BC2sXlt1Gitrg%3D, PID: 26698697

- Semaan, G.
  **10 μJ dissipative soliton resonance square pulse in a dual amplifier figure-of-eight double-clad Er:Yb mode-locked fiber laser**
  (2016) *Opt. Lett.*, 41, pp. 4767-4770.
  COI: 1:CAS:528:DC%2BC1cXlsVarsrw%3D, PID: 28005888

- Kharitonov, S., Brès, C.-S.
  **All-fiber dissipative soliton resonance mode-locked figure-9 thulium-doped fiber laser**
  (2017) *The European Conference on Lasers and Electro-Optics CJ_13_4*,
  (Optical Society of America

- Wu, Y., Tian, J.-R., Dong, Z., Liang, C., Song, Y.-R.
  **Generation of two dissipative soliton resonance pulses in an all-anomalous-dispersion regime thulium-doped fiber laser**
  (2019) *IEEE Photon. J.*, 11, pp. 1-8.
  COI: 1:CAS:528:DC%2BC1MXhtlGksbjL

- Wang, H.
  **2080 nm long-wavelength, high-power dissipative soliton resonance in a dumbbell-shaped thulium-doped fiber laser**
  (2019) *Chin. Opt. Lett.*, 17, p. 30602.

- Zhao, K.
  **High-energy dissipative soliton resonance and rectangular noise-like pulse in a figure-9 Tm fiber laser**
  (2018) *Appl. Phys. Express*, 12, p. 12002.
  COI: 1:CAS:528:DC%2BC1MXnsVKhtL8%3D

- Tan, S., Wei, X., Kang, J., Wong, K.K.Y.
  **Dissipative soliton resonance in thulium-doped fiber laser and its application for microscopy**
  (2016) *In 2016 Conference on Lasers and Electro-Optics (CLEO)*, pp. 1-2.
  (IEEE

- Ibarra-Escamilla, B.
  **Dissipative soliton resonance in a thulium-doped all-fiber laser operating at large anomalous dispersion regime**
  (2018) *IEEE Photon. J.*, 10, pp. 1-7.

- Xu, Y.
  **Dissipative soliton resonance in a wavelength-tunable thulium-doped fiber laser with net-normal dispersion**
  (2015) *IEEE Photon. J.*, 7.

- Zhao, J.
  **100 W dissipative soliton resonances from a thulium-doped double-clad all-fiber-format MOPA system**
  (2016) *Opt. Express*, 24, p. 12072.
  COI: 1:CAS:528:DC%2BC2sXmtl2nsb0%3D, PID: 27410128

- Ahmad, H.
  **Mixed transition metal dichalcogenide as saturable absorber in ytterbium, praseodymium, and erbium fiber laser**
  (2018) *IEEE J. Quantum Electron.*, 54, pp. 1-9.

- Ahmad, H., Aidit, S.N., Ooi, S.I., Tiu, Z.C.
  **All-fiber, wavelength-tunable ultrafast praseodymium fiber laser**
  (2018) *Chin. Opt. Lett.*, 16, p. 121405.

- Guy, M.J., Noske, D.U., Boskovic, A., Taylor, J.R.
  **Femtosecond soliton generation in a praseodymium fluoride fiber laser**
  (1994) *Opt. Lett.*, 19, pp. 828-830.
  COI: 1:CAS:528:DyaK2cXmvV2isrs%3D, PID: 19844459

- Ahmad, H., Aidit, S.N., Tiu, Z.C.
  **Multi-wavelength Praseodymium fiber laser using stimulated Brillouin scattering**
  (2018) *Opt. Laser Technol.*, 99, pp. 52-59.
  COI: 1:CAS:528:DC%2BC2sXhsF2hs7rJ

- Song, Y.W., Set, S.Y., Yamashita, S., Goh, C.S., Kotake, T.
  **1300-Nm pulsed fiber lasers mode-locked by purified carbon nanotubes**
  (2005) *IEEE Photon. Technol. Lett.*, 17, pp. 1623-1625.
  COI: 1:CAS:528:DC%2BD2MXpsVWntbg%3D

- Firstov, S.V.
  **Compact and efficient O-band bismuth-doped phosphosilicate fiber amplifier for fiber-optic communications**
  (2020) *Sci. Rep.*, 10, pp. 1-9.
  COI: 1:CAS:528:DC%2BB3cXhtlyjurrI

- Thipparapu, N.K., Umnikov, A.A., Barua, P., Sahu, J.K.
  **Bi-doped fiber amplifier with a flat gain of 25 dB operating in the wavelength band 1320–1360 nm**
  (2016) *Opt. Lett.*, 41, pp. 1518-1521.
  COI: 1:CAS:528:DC%2BC1cXkvFersrg%3D, PID: 27192276

- Melkumov, M.A.
  **25 Gb s<sup>−1</sup> data transmission using a bismuth-doped fibre amplifier with a gain peak shifted to 1300 nm**
  (2018) *Quantum Electron.*, 48, p. 989.
  COI: 1:CAS:528:DC%2BC1MXjt1KitL8%3D

- Dianov, E.M.
  **Bismuth-doped fibre amplifier for the range 1300–1340 nm**
  (2009) *Quantum Electron.*, 39, p. 1099.
  COI: 1:CAS:528:DC%2BC3cXmsFehu7s%3D

- Gumenyuk, R.
  **1.32 μm mode-locked bismuth-doped fiber laser operating in anomalous and normal dispersion regimes**
  (2013) *Opt. Lett.*, 38, pp. 4005-4007.

- Khegai, A.M.
  **Picosecond bismuth fibre laser mode-locked by a nonlinear loop mirror**
  (2016) *Quantum Electron.*, 46, p. 1077.
  COI: 1:CAS:528:DC%2BC2sXpsFagu7k%3D

- Thipparapu, N.K.
  **Bismuth-doped all-fiber mode-locked laser operating at 1340 nm**
  (2017) *Opt. Lett.*, 42, pp. 5102-5105.
  COI: 1:CAS:528:DC%2BC1cXit1GntrzP, PID: 29240147

- Khegai, A.
  **Bismuth-doped fiber laser at 1.32 μm mode-locked by single-walled carbon nanotubes**
  (2018) *Opt. Express*, 26, pp. 23911-23917.
  COI: 1:CAS:528:DC%2BC1cXisVKmtLfK, PID: 30184885

- Batjargal, O., Ou, Y.-H., Keikens, K., Barton, J.K., Kieu, K.
  **All-fiber dissipative soliton Raman laser based on phosphosilicate fiber**
  (2018) *IEEE Photon. Technol. Lett.*, 30, pp. 1846-1849.
  COI: 1:CAS:528:DC%2BC1MXhsFGrsbfI

- Kharenko, D.S., Efremov, V.D., Evmenova, E.A., Babin, S.A.
  **Generation of Raman dissipative solitons near 1.3 microns in a phosphosilicate-fiber cavity**
  (2018) *Opt. Express*, 26, pp. 15084-15089.
  COI: 1:CAS:528:DC%2BC1cXitlyjsbrO, PID: 30114760

- Chung, H.-Y.
  **Megawatt peak power tunable femtosecond source based on self-phase modulation enabled spectral selection**
  (2018) *Opt. Express*, 26, pp. 3684-3695.
  COI: 1:CAS:528:DC%2BC1cXitlajtrnE, PID: 29401895

- Qin, Y.
  **Watt-level all-fiber optical parametric chirped-pulse amplifier working at 1300 nm**
  (2019) *Opt. Lett.*, 44, pp. 3422-3425.
  COI: 1:CAS:528:DC%2BC1MXit1aqu7nI, PID: 31305538

- Zhao, G.-K.
  **Dissipative soliton resonance in Bismuth-doped fiber laser**
  (2017) *Opt. Express*, 25, pp. 20923-20931.
  COI: 1:CAS:528:DC%2BC1cXltlKis7Y%3D, PID: 29041768

- Pottiez, O.
  **Multiple noise-like pulsing of a figure-eight fibre laser**
  (2013) *Laser Phys.*, 24, p. 15103.
  COI: 1:CAS:528:DC%2BC2cXlsVOmtbo%3D

- Smirnov, S., Kobtsev, S., Kukarin, S., Ivanenko, A.
  **Three key regimes of single pulse generation per round trip of all-normal-dispersion fiber lasers mode-locked with nonlinear polarization rotation**
  (2012) *Opt. Express*, 20, pp. 27447-27453.
  COI: 1:CAS:528:DC%2BC38XhvVyjtbjE, PID: 23187603

- Lyu, Y.
  **Multipulse dynamics under dissipative soliton resonance conditions**
  (2017) *Opt. Express*, 25, pp. 13286-13295.
  COI: 1:CAS:528:DC%2BC1cXmvV2itLo%3D, PID: 28788864

- Goda, K., Jalali, B.
  **Dispersive Fourier transformation for fast continuous single-shot measurements**
  (2013) *Nat. Photon.*, 7, pp. 102-112.
  COI: 1:CAS:528:DC%2BC3sXhs1Chs7k%3D

- Zou, J., Dong, C., Wang, H., Du, T., Luo, Z.
  **Towards visible-wavelength passively mode-locked lasers in all-fibre format**
  (2020) *Light Sci. Appl.*, 9, pp. 1-10.
  COI: 1:CAS:528:DC%2BB3cXjtlaitQ%3D%3D

- Li, D., Tang, D., Zhao, L., Shen, D.
  **Mechanism of dissipative-soliton-resonance generation in passively mode-locked all-normal-dispersion fiber lasers**
  (2015) *J. Light. Technol.*, 33, pp. 3781-3787.
  COI: 1:CAS:528:DC%2BC2sXkvVait7c%3D

- Chang, W., Ankiewicz, A., Soto-Crespo, J.M., Akhmediev, N.
  **Dissipative soliton resonances in laser models with parameter management**
  (2008) *JOSA B*, 25, pp. 1972-1977.
  COI: 1:CAS:528:DC%2BD1cXhsFWrtrrE

- Chang, W., Soto-Crespo, J.M., Ankiewicz, A., Akhmediev, N.
  **Dissipative soliton resonances in the anomalous dispersion regime**
  (2009) *Phys. Rev. A*, 79, p. 33840.
  COI: 1:CAS:528:DC%2BD1MXktVyltLo%3D

- Li, Z.
  **Multiple stable states of dissipative soliton resonance in a passively mode-locked Yb-doped fiber laser**
  (2019) *Appl. Opt.*, 58, pp. 6841-6847.
  COI: 1:CAS:528:DC%2BB3cXhtFKhtrY%3D, PID: 31503654

- Ahmad, H., Aidit, S.N., Tiu, Z.C.
  **Dissipative soliton resonance in a passively mode-locked praseodymium fiber laser**
  (2019) *Opt. Laser Technol.*, 112, pp. 20-25.
  COI: 1:CAS:528:DC%2BC1cXitFChur7I


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